UG0659
User Guide
Encoder Interface v4.1

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Contents

Figures

Tables

1 Revision History

The revision history describes the changes that were implemented in the document. The changes are listed by revision, starting with the most current publication.

1.1 Revision 3.0

The following is a summary of the changes in revision 3.0 of this document.

- Added the IP version to the document title.
- Added speed_done_o and speed_filter_done_o output signals in Figure 5, page 5 and Table 1, page 6.
- Removed Configuration Parameter section from Hardware Implementation, page 5.

1.2 Revision 2.0

Updated the document based on SAR 80420.

1.3 Revision 1.0

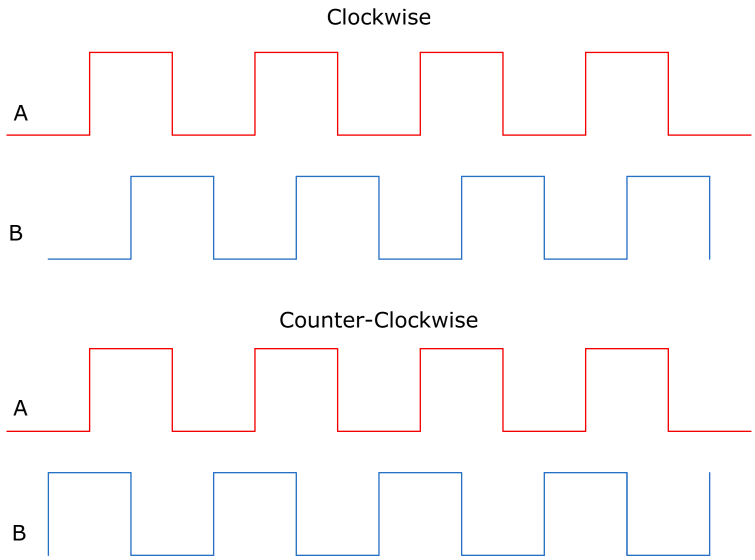
Revision 1.0 was the first publication of this document.

2 Introduction

Incremental encoder is the most common sensor used for field oriented control (FOC) of permanent magnet brush less DC (BLDC) or permanent-magnet synchronous motor (PMSM). This sensor gives relative angular position as the output in the form of pulses. A quadrature encoder, typically produces two outputs, which have pulses phase shifted by 90°, as shown in Figure 1, page 2. The phase shift between the two signals A and B represents the direction of rotation. The encoder interface logic uses edge detection on rising edge and falling edge of A and B, as shown in Figure 2, page 2. This gives a resolution that is four times the encoder resolution and produces a very high resolution from a low cost encoder.

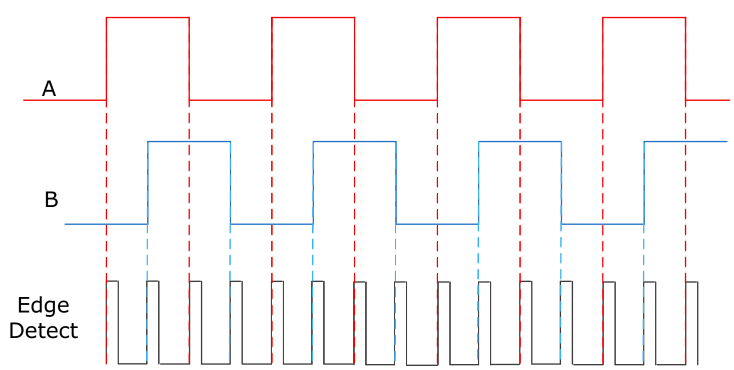
The following figure shows the encoder signals in clockwise and counter-clockwise directions.

Figure 1 • **Encoder Signals in Clockwise and Counter-clockwise Directions**



The following figure shows the edge detection of encoder pulses for higher resolution.

Figure 2 • **Edge Detection of Encoder Pulses for Higher Resolution**



After the edge detection, counters are used to get a rotor angular position in terms of an electrical angle so that, it can be directly used for FOC. The Angle_count_max value represents the total number of edges that will be detected in one mechanical rotation of the rotor. The angle output ranges from 0 to 262143, where 262143 represents 360°. The variation of angle output with respect to the edges is shown in Figure 3, page 3 for positive speed and Figure , page 4 for negative speed. The speed output is calculated based on the rate of change of angular position.

Three parameters are used to configure the encoder interface:

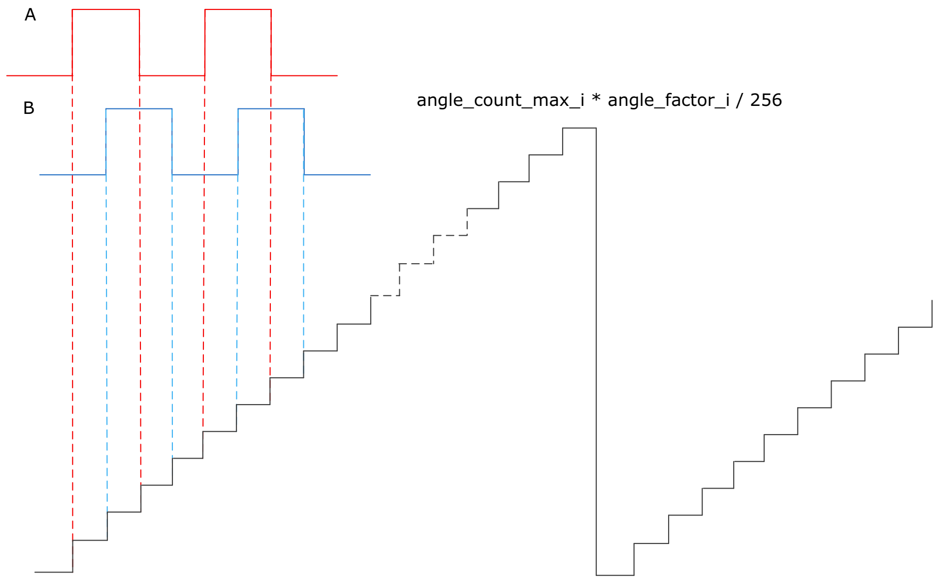
$$\text{Angle Factor} = \frac{256 \times 262144 \times \text{Number of pole pairs}}{\text{Encoder Reslution} \times 4}$$

$$\text{Speed Factor} = \frac{384000}{\text{Encoder Resolution}}\text{RPM} = \frac{384000 \times 65536}{\text{Encoder Resolution} \times \text{Rated Speed}}(\text{p} \cdot \text{u})$$

$$\text{Angle Count Max} = 4 \times \text{Encoder Resoultion} - 1$$

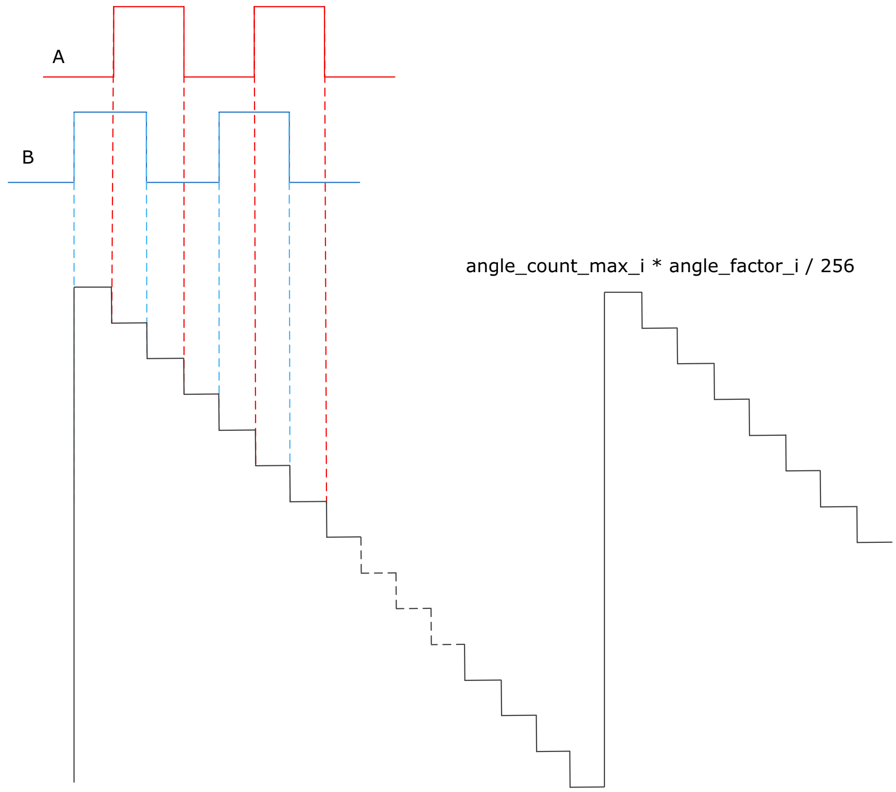
The following figure shows the Theta output for the positive direction.

Figure 3 • **Theta Output for Positive Direction**



The following figure shows the Theta output for the negative direction.

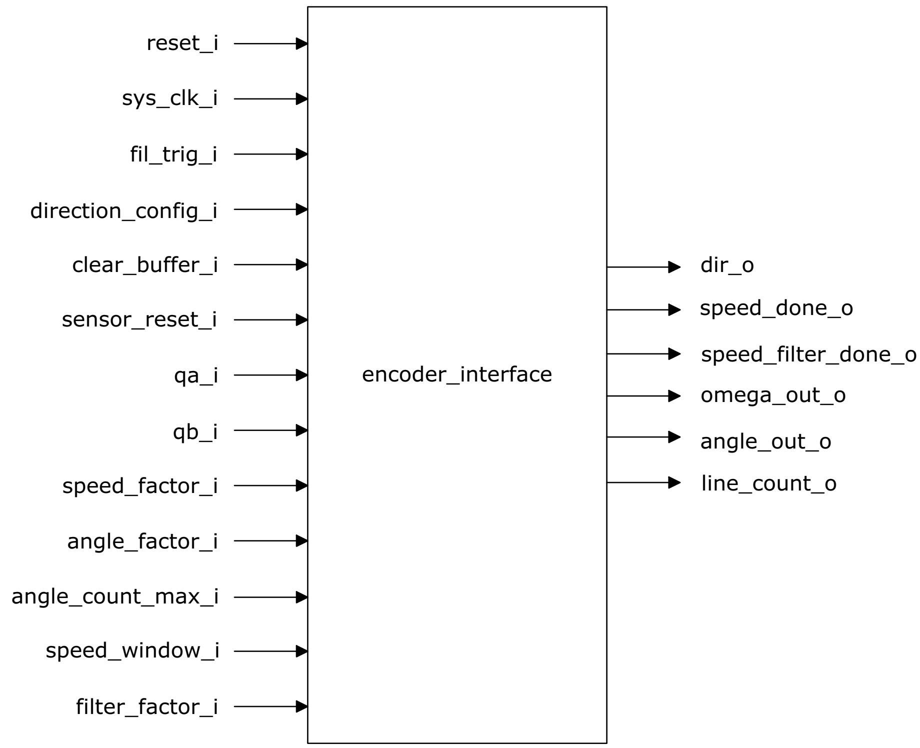
Figure 4 • **Theta Output for Negative Direction**



3 Hardware Implementation

The following figure shows the block diagram of encoder interface.

Figure 5 • **System-Level Block Diagram of Encoder Interface**



The encoder interface block converts signals received from QA, QB into its corresponding angle and speed. The block counts encoder edges till the angle_count_max_i value is attained and then starts counting from zero again. The angle generated is scaled to 262144 by multiplying it with the angle_factor_i. Speed is measured by counting the number of encoder events in a constant time period defined by speed_window_i input. A filter is used to filter the quantization noise from speed measurement. The filter time constant can be configured using the filter_factor_i value using the following equation:

$$\text{Filter time constant} = \text{Time period between successive pulses of pwm midmatch\_i} \times 2^{\text{filter\_factor\_i}}$$

The sensor_reset_i input is used to find motor electrical angle by injecting constant current for a small duration. When the motor has aligned to the injected angle, the encoder output is initialized with 90° or 270° based on initial direction of rotation. The encoder edge counting is expected to start after the falling edge of the sensor_reset_i input is detected.

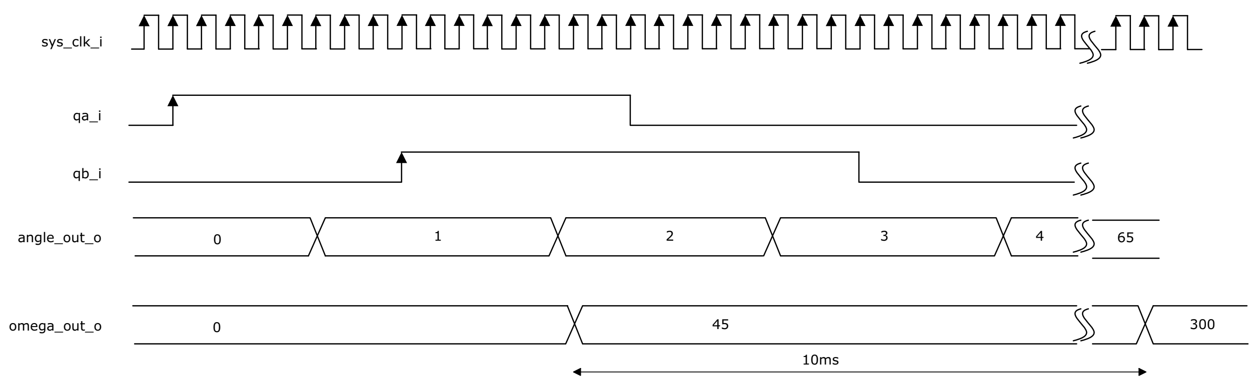
The clear_buffer_i input can be used to reset the filter buffer, as the filter buffer is expected to be reset when the motor stops.

The direction_config_i input is used to initially detect the motor direction. Once the motor starts running, the motor direction is detected from the encoder signals and used in generating the angle.

3.1 Timing Diagram

The following figure shows the timing diagram of the encoder interface.

Figure 6 • **Timing Diagram of the Encoder Interface**



3.2 Inputs and Outputs

The following table lists the input and output ports of encoder interface.

Table 1 • **Inputs and Outputs of Encoder Interface**

Signal Name	Direction	Description
reset_i	Input	Active low asynchronous reset signal
sys_clk_i	Input	System clock
fil_trig_i	Input	Filter trigger input. A timing pulse of one clock cycle width should be provided at this input. The periodicity of the pulse determines the sampling time.
direction_config_i	Input	Direction configuration bit - used at calibration time to align the rotor. When 1, aligns rotor for counter clockwise starting or when 0, aligns rotor for clockwise starting.
clear_buffer_i	Input	Clears the filter buffer generally when the motor is stopped. A pulse of one clock cycle width should be input each time the motor stops.
sensor_reset_i	Input	Sensor Reset signal: When set to 1, rotor angle is reset to the equivalent of 90° or 270° as determined by the direction_config_i input. When set to 0 (zero), normal operation.
qa_i	Input	Encoder input A
qb_i	Input	Encoder input B
speed_factor_i	Input	Speed output scaling multiplier
angle_factor_i	Input	Angle output scaling multiplier
angle_count_max_i	Input	Maximum angle count value in terms of encoder pulse events.
speed_window_i	Input	The time window for speed computation, specified in multiples of 10 µs. Larger time window gives better speed resolution but has higher latency. Smaller time window must be used for high dynamic speed response.
filter_factor_i	Input	Filter factor value for filter – if value is n, the filter time constant is 2^n times the sampling time of the filter defined by filt_trig_i.
dir_o	Output	Direction signal generated based on encoder input signals.
speed_done_o	Output	Indicates speed computation is ready for filtering (at the end of speed window). A pulse of one sys_clk_i cycle width is generated.

Table 1 • **Inputs and Outputs of Encoder Interface *(continued)***

Signal Name	Direction	Description
speed_filter_done_o	Output	Indicates speed output after filtering is valid (at omega_out_o output port). A pulse of one sys_clk_i cycle width is generated.
omega_out_o	Output	Rotor speed output after filtering - suitable for use as speed feedback in speed control operation.
angle_out_o	Output	Electrical angle output suitable for FOC.
line_count_o	Output	Specifies the rotor position in terms of number of encoder lines (increments) since the last sensor reset. Suitable for use with position control operations.

3.3 Resource Utilization

Encoder interface is implemented on the SmartFusion®2 system-on-chip (SoC) field programmable gate array (FPGA) device. The following table lists the resource utilization report after synthesis.

Table 2 • **Resource Utilization Report of the Encoder Interface**

Cell Usage	Count
Sequential elements	330
Combinational logic	540
MACC	2
RAM1Kx18	0
RAM64x18	0